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Important challenges for 10 MW reference wind turbine from RAMS perspective

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Abstract

Objective: To identify important challenges which are necessary to overcome for conducting the RAMS (Reliability, availability, maintainability and safety) analysis in an efficient and cost effective way.
Methodology: RAMS analysis has become an active area of research to measure the efficiency of any operational system for evaluating its performance as per its designed features. The accuracy of measurements and analysis heavily depend upon how the RAMS related issues and challenges are addressed before planning the operational strategies to enhance the system availability for power output. It means that different RAMS related aspects are to be identified in congruent with the start of the design for a new product. So for providing sound basis for RAMS related analysis, an investigation has been carried out to identify important challenges which need to be addressed for having a robust and cost effective product satisfying the design parameters and operational strategies in a holistic way. For this purpose 10 MW reference wind turbine has been selected as a case study which is in the conceptual design phase now a day. For highlighting important challenges and issues, the framework has been developed to see how the design choice influences the operations. Moreover the particular design choice could also get feedback from operations to make new generations of the product in a better and innovative way.
Results (expected): The feedback being acquired from the operational phase will provide basis to conduct the finite element and fatigue load analyses to find the areas prone to higher stress concentration. Based on such information, necessary modifications and improvements could be suggested for latest versions of that product. Maximum power capacity of existing wind turbines is 5 MW and to double the output of such machines is not a simple scaling problem. So the identification of important RAMS challenges and issues are directly helpful to solve such scaling problems to make these new machines more reliable and consequently more attractive for investors. The integration of design process and RAMS aspects in the proposed way will end in harmonizing and solving the scaling issues for bigger machines even beyond 10 MW reference wind turbine and making them viable from operational and investment point of view.

Keywords: RAMS parameters; design; operation; framework; reference wind turbine

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1. Introduction

From last few decades, there is a trend of shifting the wind turbines from land to sea due to number of reasons like more wind is available in offshore environment compared to the same on land. Additionally, the installations of wind turbines are not welcomed by the local community near their homes due to number of negative psychological consequences. So the shift from onshore to offshore locations for wind turbines has posed new challenges from the design to operation and logistics. The installation and operational strategies seem complex and sophisticated in terms of transportation, access, and safety issues. The question arises how we can compensate the complexity and sophistication of offshore wind turbines (OWT). There are number of possibilities to extract maximum energy from OWT by installing them in big arrays or by using the large size of OWT. Every option has its advantages coupled with disadvantages. For example in the former case, standard size of wind turbines like 5 MW could be used which are technological proven choices but their large number of arrays will consume lot of resources to maintain them. On other hand, the installation of OWT of having size greater than 5 MW will produce more energy with less resources for maintenance but its technology is still in the development phase which may take number of years to become viable. If larger wind turbine like 8, 10 or 20 MW wind turbine could be developed with reliable technology, then there are high chances that their installation in an offshore environment will be paid back efficiently. The rational is quite simple that more wind is available at sea and it will be hugely exploited by the larger wind turbine like 10 or 20 WT than to do the same for an array of small size wind turbines.

In the coming section, the bases of 10 MW wind turbines have been highlighted before outlining a generic framework afterwards. Afterwards, the challenges for a 10 MW wind turbine have been identified. At the end, conclusions are drawn.

2. Basis of 10 MW Wind Turbine

The question arises in mind why to have 10, 20 MW or even larger wind turbines? There could be plenty of reasons for up scaling the existing 5 MW machine to 10 and 20 MW for exploiting the maximum wind potential available in the deeper sea. Moreover this scaling up is full of new challenges to introduce novel concepts in the blade design, nacelle weight reduction, new control strategies for larger wind machines, huge support structures and complex and intricate operational and maintenance strategies. UpWind project [1] , a collaboration work of Netherland's ECN and Denmark's RISØ Laboratories, has assessed the difference between the parameters of the up scaled wind turbines with the reference 5 MW machine. They scaled up the reference 5 MW wind turbine to 10 MW and then progressively the design parameters for 20 MW were evolved. The largest concepts which are now on the drawing board measure close to 150 m rotor diameter and have an installed power capacity of 10 MW. While a 10 MW concept progressively took shape, UpWind sets its mind to a larger wind turbine, a turbine of about 250 m rotor diameter and a rated power of 20 MW.

The new proposed machines of 10 and 20 MW by UpWind seems of similar shape like three blades and exposure to wind loads from the up side of blades. The change in rotor diameter with reference to 5 MW wind turbine is less in 10 MW machine compared to the same for 20 MW one. The difference in rotor mass of 5, to 10 MW is almost three times but that of the same from 10 to 20 MW is just more than double. The increase in tower top mass is quite significant while moving from 5 to 10 MW but it is small from 10 to 20 MW. The tower mass is increasing three times while moving from 5 to 10 and 20 MW wind turbines respectively. The comparison of 10 and 20 MW wind turbines vis-à-vis 5 MW shows that large amount of power is expected from larger machines. The increase in wind turbine size seems paying off but with more weight of nacelle, tower and foundations. More weight means more complicated control, installation and operational strategies which pose new challenges and hurdles in making the 10 and especially 20 MW machines technically and economically feasible.

3. Generic Framework

Design process and RAMS aspects are intertwined with each other as shown in Fig.1. Any kind of feedback from the RAMS activities will be directly helpful in overcoming the shortcomings of existing design or to improve the latest generations of the same one. It is obvious that the performance of a new designed product will be influenced by the operational conditions, levels of reliability achieved to maintain it and the quality of the maintenance and inspections being carried out, and the safety issues for the personnel during the working. The failure frequencies and the accompanied duration of downtimes at the assembly and subassembly level will provide a sound basis to the designer for carrying out improvements based on these results. So the improvement in the design process and the feedback from the RAMS activities will be dynamic in nature which will start a cycle of continuous improvement for having a more reliable and innovative products based on the real time feedback provided from the operations. Keeping in view the strong relationship of design and RAMS, it is important to have a kind of framework to see and evaluate the influence of decision, to opt for a certain type of design choice, on the operational process. It is important to know the availability levels of certain type of wind turbine to extract the maximum potential of wind energy. So a generic framework is presented below in a simplified fashion to develop the link among the decision, performance and value nodes. Here decision node means all kind of decisions taken during the design process which will influence the operations. Performance nodes are those ones which are directly or indirectly related influencing the strategies being adopted to handle the reliability and maintenance strategies. The cumulative impact of decision and performance variables will determine the overall operational cost.

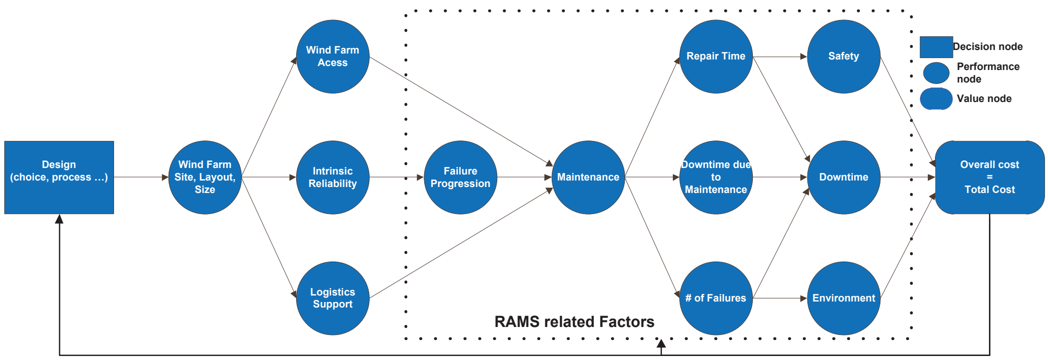

Fig. 1: An illustration showing the relationship of design and RAMS parameters for offshore wind turbines

The framework in Fig. 1 starts from developing or choosing a particular design type of wind turbine. Given that a certain kind of wind turbine has been selected to be installed, then this choice will affect the site selection, wind farm layout and its size. Due to the nature of wind load, it may be possible that certain site will be ideal for upwind turbine and other will be excellent for vertical axis wind turbines. So a particular choice of design will have a direct impact on the site and wind farm configuration. Normally the available wind turbines are installed in a particular form of array but it may be possible that the wind turbines like 10 MW may produce better results if they will be placed in a random way to be least influenced from the neighboring wind turbine. When the wind turbine is being put into operational phase, then its real behavior will be revealed in terms of its built-in reliability levels. The achieved reliability levels will be influenced by the wake effect of other wind turbines in the same vicinity and what kind of condition monitoring system (CMS) is being employed to monitor the overall health of the wind turbines. All these factors determine what kind of maintenance strategy must be adopted which will influence the repair time, down time , safety and other such variables following the maintenance factor as shown in Fig.1. In short the choice of a particular design will influence the RAMS related factors and cumulative impact of all these decision and performance related variables will determine the overall operational cost. The operational cost will be reflected by value node and the necessary feedback will be provided to evaluate the viability of the adopted maintenance strategy. The same feedback process from the value node will be provided to the designer to see how much cost was incurred by their chosen design type and if needed, what should be the corrective measures to overcome the shortcomings of the existing design.

4. Important challenges

The whole cycle of new product development encounters plenty of challenges ranging from securing initial investment for concept evaluation, developing novel and cost effective design and finding customers to buy it. Keeping in view the up scaling of current wind turbine of 5 to 10 MW, there could be plenty of new challenges and important of them have been highlighted here.

4.1. Investment

This is the important step in the design and development phase of the new product. It shows the receptiveness of the investors to the new idea and how they think get benefit from it. For a novel idea, sometimes it becomes a gigantic task to find the investors who will sponsor the research and development cost of the new product. It has been found out by [2] that the investors, bankers, and insurance companies demand “proven technology” for the wind turbines to be used in (future) offshore wind farms. Probably they are willing to accept the current largest land based machines (2.5 MW) as “proven technology” at the time the offshore projects of the size of a power plant (typically 500 MW) will be built. But it is very questionable that they will be willing to invest and/or insure a GigaEuro project incorporating new 5 MW dedicated offshore wind turbines. It means that like one decade ago, the investment institutions were not considering the 5 MW wind machine as “proven technology” and were reluctant to take risk for its sponsorship. But now 5 MW machine is considered as reliable for offshore environment. At this moment the same psychological phenomena is going on with 10 and 20 MW wind machines to find new investors.

4.2. Design

Feasibility and choice of a certain type of design type has a deep impact on the reliability and availability levels of the wind turbines. Based on the technical skill and experience at hand, what will be the optimal choice is an important issue to be explored. Different types of designs choices are available like, upwind or downwind, horizontal axis or vertical axis, pitch or yaw controlled. It is important to decide what will be the optimal one for a new product. In the upwind project [1], it has been found out that rather than using full pitch control, where the whole blade can be controlled and moved depending on the wind, they found that with the really large wind turbines have to mimic an aeroplane or a bird, using smart control on a blade that has a "flap" on its trailing edge that moves separately. It was found that this could reduce the weight of the blade by up to 25%. So in terms of control, it has been proposed to use new type of control system rather than sticking to the old fashioned pitch control system. This is one typical example but there could also be many more such possibilities for larger wind machines compared to the smaller ones. From the RAMS point of view there are number of concepts which could be considered during the design phase like one was about self-maintenance machines being proposed by [3]. This concept is to introduce the redundancy during the design phase of the system to make it capable of readjusting itself in case of failure of a certain component or assembly. Important inputs to this concept are the RAMS data and FMECA (Failure mode effect and criticality analysis) studies of the system. It is important to look deep into such kind of concepts to evaluate their viability for such large machines of 10 and 20 MW machines. Moreover the framework presented in Fig. 1 could be used to act as a yardstick to estimate the expected impact of a certain type of design for larger machines on the RAMS related factors and their accompanied costs.

4.3. Wind farm

The site, size and layout of wind farm play pivotal role in evaluating the feasibility of a certain type of wind turbine. The location of site will determine how much cost has to be paid to transport and access it for installation and operation purposes. The choice of a particular site may render one design choice unattractive in offshore environment due to logistics and access needed to install and maintain the wind turbines. For example it has been concluded by [4] that a single turbine can require up to 8 loads (one nacelle, one hub, three blades and three tower sections). For an entire project of 150 MW, transportation requirements have been as much as 689 truckloads, 140 railcars and 8 vessels to the United States. It is no wonder that one of the biggest challenges facing the industry are the logistics of transporting such oversized parts sometimes over extremely long distances. If such long distances are from the fabrication sites to deep into sea and given that huge weights of larger wind turbines, any miscalculation in selecting a certain site may have disastrous impact on the feasibility of selected type of machine. In addition to logistic support, the higher levels of access will have favorable impact on the availability of OWT. Size and layout will be responsible to estimate the wake effects on a given array of wind farm. It has been investigated by [5] that in a 200 wind turbine array, the increase of 0.1m/second wind speed will increase the net present value of the project to $20 million if the cost of each kWh is worth $0.10 to the producer. Moreover, the size and layout of the wind farm are responsible for exploiting the benefits of the available wind loads at the particular selected site. But the size of wind turbine has direct influence on the overall smooth operations because enhancing the quantity of turbines will require more access and logistics support for visits to conduct the inspection and repair tasks. Another constraining factor on the size and layout is the handling of wake effect which needs to be minimized because it produces negative impact on the overall energy production and lowered the reliability levels of wind turbines.

4.4. Condition monitoring system (CMS)

The architecture of CMS is another important aspect which needs to be given its due share during the design of a new wind turbine. CMS is employed on the land and offshore wind turbines for estimating the condition of the component and remote surveillance of the wind farm. New concepts, for example to declare few of the wind turbines in the wind farm as flight leader, has been proposed [1]. Now it is important to evaluate which choice is feasible for larger wind turbines like traditional CMS or flight leader concept. The quality and efficiency of CMS has a direct impact on the reliability levels of wind turbines. Condition monitoring of important components and assemblies will provide important data to statistically analyze their state before conducting any kind of inspection or maintenance tasks. Moreover the information provided by CMS will provide basis to declare when to conduct the renewal of the system. So for larger wind turbines, such kind of decisions are of vital importance to arrange necessary logistic and access support to undertake any desired task.

4.5. Failure rates and operational strategies

What kind of failure statistics on component and assembly level will be shown by the larger wind turbines is vital to evaluate the strengths and weaknesses of the chosen design type. For a traditional land based wind turbines, failure frequencies were higher for electrical components with less accompanied downtime but entirely reverse case with mechanical components which was investigated by [6]. For land based machines, the replacement and repair of mechanical system likes gearbox is not costly as compared to offshore environment. The transportation and especially lifting costs are quite expensive at sea, and then any serious repair or replacement of heavy duty mechanical systems will consume lot of financial resources. To get rid of such heavy mechanical assemblies like gearbox, direct drive machines have been proposed. But the failure statistics collected by [7] have revealed that direct drive machines are more failure prone compared with those of having gearbox. Moreover it was found out that machines with fewer components called as robust design are more reliable in terms of failure rates. So keeping in view such study results, does the designer of larger wind turbines of 10 or 20 MW should opt for direct drive or to introduce the robustness in the design. It is not easy to answer such question because the study was conducted almost one decade ago and from that time till now, lot of innovations have been carried out in the wind industry. Important thing is to do the tradeoff among using the direct drive and robust design in terms of reliability and lifting costs. In this way, some deep insight into this issue will provide basis to reach an optimal decision. Operational and maintenance (O&M) cost is about 25% of the levelised production costs as indicated by [8]. It means one quarter of the production cost is consumed in managing the operational and maintenance activities of the wind farm. There are number of ways to handle O&M issues by developing and implementing the novel strategies. One strategy could be to group different inspection and maintenance activities together to share the setup costs with maximum components. It has been shown by [9] that by grouping different inspection and maintenance task for wind turbine could save 10% as compared to the same tasks doing without grouping. Different aspects of O &M strategies have been discussed by [10-13] where they have covered economics, maintenance optimization and opportunities for conducting the maintenance work. It is an important question whether these strategies presented for 5 MW will be relevant for larger machines of 10 or 20 MW machines. This is another area of challenge which requires special attention to reduce the overall operational cost to maximize the profit.

4.6. Power predictions

The expected amount and time of power production are important factors which could provide valuable information to meet the expected demand and to carry out the inspection and repair tasks. There could be many more implications for knowing in advance the expected power output and its time. Artificial neural network (ANN) or other techniques might be used to predict the power output based on the historical data. In a given array of offshore wind farm, the said task was accomplished by using ANN and some of the results for four wind turbines located at different location within the single wind farm are shown in Fig.2. The accuracy of predicted power output is more than 95% with maximum MAPE (Mean average percentage error) is 4.41%. Moreover the information is available when the expected power output will be maximum and minimum for every wind turbine. It means that few of the wind turbines with in a given array of wind farm might behave similarly which could be clustered together. We know the predicted power output at hand, and then we can plan the O&M strategies in an optimal way. Additionally the availability levels of wind turbines and the amount of profit could also be estimated. It is important to evaluate such prospects for the larger machines like 10 MW.

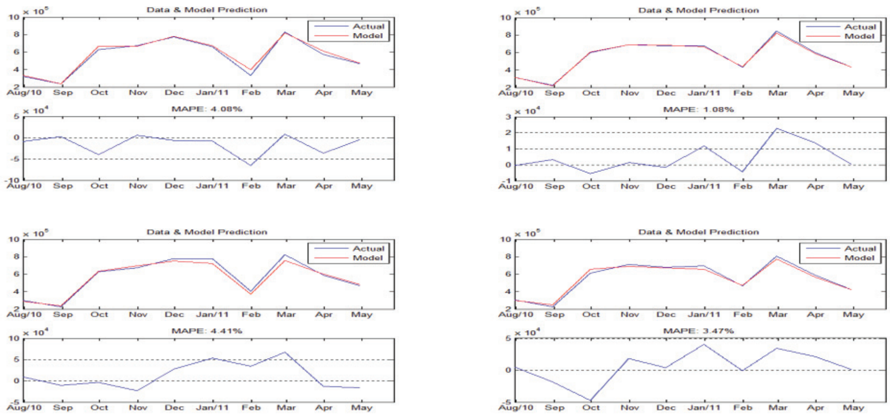

Fig.2: Power prediction of offshore wind turbines using artificial neural network

5. Conclusions

Consideration of RAMS aspect during the design phase of larger wind turbines of 10 and 20 MW may prove fruitful in designing and developing a more reliable and efficient machine. When the systems which are prone to failure will be replaced with the ones having higher reliability, then these larger machines will get more market share.

By addressing the RAMS related challenges at the starting phase, the availability of larger machines could be enhanced and consequently the renewables energy will get more attention and focus from the potential investors. Challenges in having larger machines more reliable and efficient are gigantic and which requires innovation and novel ways to handle them.

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